Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Procedia Engineering 64 (2013) 1293 – 1301
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on DESIGN AND MANUFACTURING, IConDM 2013

Experimental Investigation and Finite Element Analysis of Filament Wound GRP pipes for Underground Applications

Gunasegaran.V[a]*, Prashanth.R[b], Narayanan.M[b]

[a]*Assistant Professor, Department of Mechanical Engineering, B.S. Abdur Rahman University, Chennai 600 048, India.*
[b]*Final year Student, Department of Mechanical Engineering, B.S. Abdur Rahman University, Chennai 600 048, India.*

Abstract

The filament winding process involving the manufacturing of composite pipes has better mechanical properties. However a number of influencing parameters may affect its mechanical behavior, which arises mainly due to its inherent property of anisotropy. In order to overcome this, many researches are progressing to optimize the process. In this paper an experimental investigation considering four process parameters and their subsequent study on the effects of the mechanical properties of filament wound Glass Reinforced Plastic (GRP) pipes was conducted. Nine 500mm pipes were manufactured based on Taguchi's Design of Experiments (DOE) Model and studied for optimization of axial tensile strength, hoop tensile strength and pipe stiffness using Taguchi's Robust Design. Analysis of Variance (ANOVA) method was also used to statistically determine the weight of each process variable on the particular response and a finite element analysis was performed using multi-layer elements for the optimized conditions to have a more realistic view of, how the pipe would behave in the operational scenario.

Keywords:Filament Winding;Glass Reinforced Plastics (GRP);Design of Experiments (DOE);Taguchi's Robust Design;Analysis of Variance (ANOVA);Finite Element Analysis.

*Corresponding author. Tel.: (+91) 876-020-7849 (mobile)
*E-mail address:*gunabaskarang@gmail.com

doi:10.1016/j.proeng.2013.09.210

1. Introduction

The advantage of composite material over conventional engineering materials stem largely from their high specific strength, stiffness and fatigue characteristics. Composite materials over the years have emerged as a strong contender for replacing steel in piping application. Glass fibre reinforced plastic pipes is the forerunner in this area due to principle features like optimized strength, mass production and the overall economics of the product.

Filament winding process is a widely adopted method for producing axis symmetric composite structures. The most common way of doing this is by wet winding, where a band of pre-impregnated glass fibres are applied onto a rotating mandrel and then the material is cured with or without the application of an external heat source.

Although composite materials have greater scope than their counterparts, they pose some critical engineering challenges due to their inherent properties of anisotropy and non-homogeneity. Hence proper designing of the material is absolutely necessary to canvas their advantages. In our case the filament winding process has number of parameters which to a greater extent affect the mechanical properties the pipe. Certain key parameters like winding angle provide information that is generally useful to explain the mechanical behaviour of the pipe. However less satisfactory predictions have been made so far regarding other process parameters. Hence an experimental investigation was undertaken to study their effects [1-2-4].

Nomenclature

n	Total number of response observations
y	Value of each response observation

2. Filament Winding Process

The filament winding process involving the manufacturing of GRP pipes is illustrated in the figure below. The filament winding machine used for experimentation is a CNC controlled two axis helical winding machine with traverse carriage motion. The resin impregnation takes place in a resin bath via a number of scissor bars which are placed on the carriage. The silica feeding takes place by means of an overhead hopper attached to the carriage.

a b

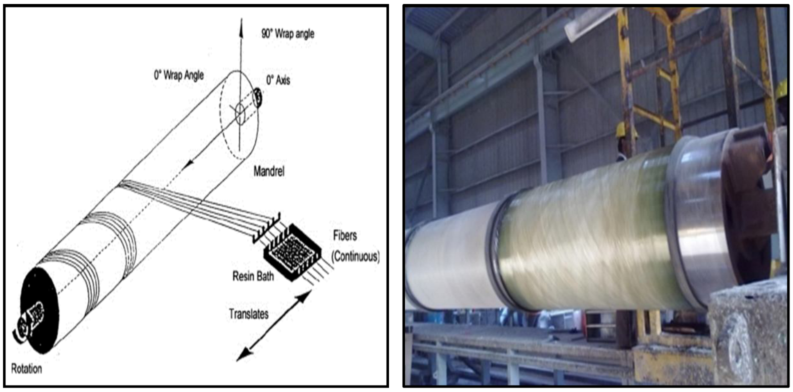

Fig.1. (a) Schematic representation of filament winding process; (b) Filament wound GRP pipe

3. Parametric Optimization

There are four process parameters which are selected as control variables for our experimentation and three mechanical properties as response variables, which are given in table 1.

Table 1.List of variables

Control variables				Response variables		
Winding angle (A)	Silica content by weight (B)	Silica particle size (C)	Fiber pretension (D)	Axial tensile strength	Hoop tensile strength	Pipe stiffness

3.1. Taguchi's Design of Experiments

Taguchi's Design of Experiments (DOE) advocates the use of Orthogonal Arrays (OA) to conduct the experiments. The number of levels of control variable is taken as three. Hence the appropriate orthogonal array for our experimentation is found out as $L_9(3^4)$ which is given in table 2. [4-6-7].

Table 2. L_9 orthogonal array

Experiment	Levels of control variable			
	Winding angle (A)	Silica content by weight (B)	Silica particle size (C)	Fiber pretension (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3.Magnitudes of control variables

Control variable	Level		
	1	2	3
Winding angle(degree) (A)	55	63	73
Silica content by weight (%) (B)	20	30	40
Silica particle size(microns) (C)	300	500	700
Fibre pretension (gms/roving) (D)	100	125	150

Nine pipes were manufactured as per Taguchi's Design of Experiments and each pipe was tested for their response variables.

3.2. Test Results

All tests were carried out in a 20 ton Universal testing machine (UTM).

3.2.1. Test for Axial Tensile Strength

The axial tensile strength is measured by following standard test procedure ASTM D638, where sectioned plate specimen is loaded to its breaking point in an UTM. The following results were obtained in MPa.

Table 4.Results for axial tensile strength

Experiment number	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5
1	36.52	38.73	38.37	38.01	39.87
2	18.65	17.72	18.76	19.31	18.16
3	25.48	24.00	25.73	24.49	25.11
4	25.06	26.20	26.52	26.39	24.94
5	23.75	24.40	22.86	22.44	23.33
6	28.88	30.15	27.66	27.95	29.46
7	25.66	26.87	27.25	27.95	26.30
8	35.37	32.66	34.14	33.05	33.82
9	16.76	15.81	15.33	16.02	16.44

3.2.2. Test for Hoop Tensile Strength

The hoop tensile strength is measured by following standard test procedure ASTM D2290, where notched ring specimens are circumferentially pulled by means of a pair of split discs. The following results were obtained in MPa.

Table 5.Results for hoop tensile strength

Experiment number	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5
1	229.51	256.79	254.65	243.13	277.89
2	112.96	103.06	115.96	109.13	123.64
3	141.03	133.02	131.57	138.60	129.96
4	222.34	234.70	243.07	265.50	254.70
5	235.85	257.70	214.09	247.47	226.16
6	158.63	181.14	176.17	169.45	189.81
7	294.62	267.30	322.51	298.94	290.30
8	249.65	266.97	296.49	273.65	279.97
9	158.39	162.75	170.56	153.59	145.53

3.2.3. Test for Pipe Stiffness

The Pipe stiffness is measured by following standard test procedure ASTM D2412, where sectioned ring specimens are loaded by a pair of plates externally. The following results were obtained in kPa.

Table 6.Results for pipe stiffness

Experiment number	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5
1	438.67	456.00	438.67	454.67	392.00
2	357.33	340.00	330.67	365.33	314.67
3	457.33	404.00	441.33	422.67	440.00
4	556.00	533.33	520.00	526.67	512.00
5	480.00	494.67	480.00	460.00	509.33
6	540.00	528.00	501.33	508.00	508.00
7	309.33	317.33	312.00	289.33	310.67
8	330.67	316.00	332.00	309.33	314.67
9	334.67	320.00	332.00	337.33	346.67

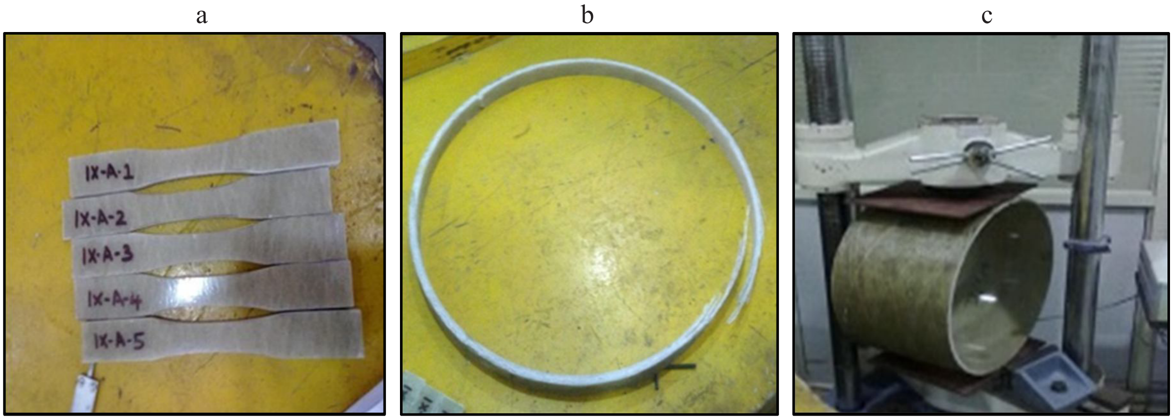

Fig.2. (a) Axial specimen; (b) Hoop specimen-fractured; (c) Stiffness testing.

3.3. Data Analysis using Taguchi Robust Model

The Taguchi robust model analyses data on the basis of Signal to Noise Ratio (S/N) which is a statistical function which combines mean and variance. The formula for S/N ratio is selected for the preferred "Larger-the-Better" condition which is given as [4-6].

$$\frac{S}{N} = -10\log[\frac{\Sigma y^2}{n}] \tag{1}$$

The S/N ratio for each of the response variables were calculated and given in table 7.

Table 7.S/N ratios for response variable

Response variable	Experiment number								
	1	2	3	4	5	6	7	8	9
Axial tensile strength	31.65	25.34	27.94	28.23	27.36	29.18	28.55	30.57	24.11
Hoop tensile strength	47.99	41.01	42.58	47.70	47.41	44.81	49.34	48.69	43.94
Pipe stiffness	52.75	50.63	52.71	54.47	53.70	54.26	49.75	50.11	50.47

From the above table, mean S/N ratios were computed at each level of the control variable to obtain the mean S/N plot.

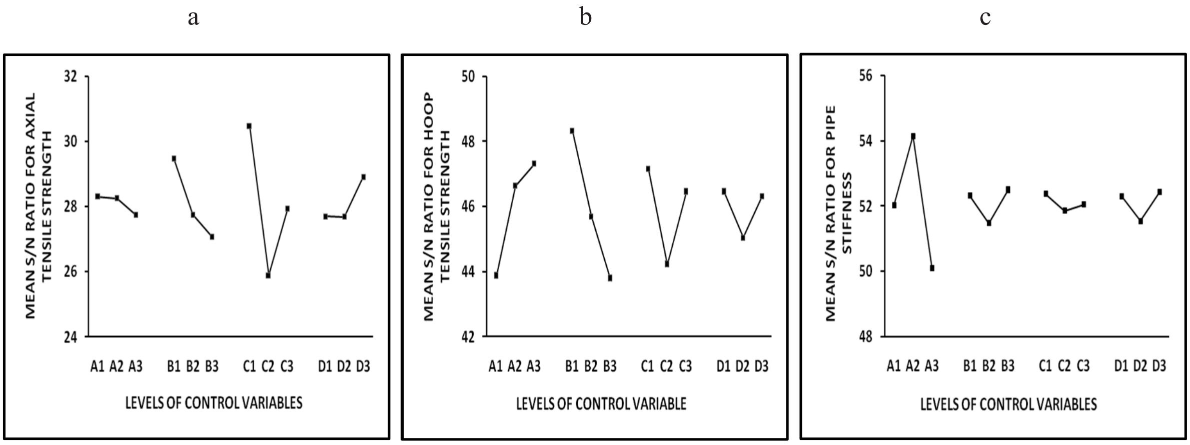

Fig. 3. (a) S/N ratio variation for axial tensile strength; (b) S/N ratio variation for hoop tensile strength;(c)S/N ratio variation for pipe stiffness.

From the above plots the optimum combinations for the respective response variables are found out as:

- Axial tensile strength : A1 B1 C1 D3
- Hoop tensile strength : A3 B1 C1 D1
- Pipe stiffness : A2 B3 C1 D3

3.4. Data Analysis using ANOVA

A single variant ANOVA and standard F test was performed using Microsoft Excel.

Table 8.ANOVA and F test for axial tensile strength

Variable (Z)	Degree of freedom (f_z)	Sum of squares (SS_Z)	Variance (V_Z)	F-ratio (F_Z)	Critical F value at 5% probability	Pure sum of squares (SS_Z')	Percentage contribution (P_Z)
Winding angle (A)	2	23.37	11.68	15.55*	3.26	21.87	1.13
Silica content (B)	2	394.55	197.27	262.48*	3.26	393.05	20.25
Silica particle size (C)	2	1402.09	701.04	932.77**	3.26	1400.59	72.16
Fibre pretension (D)	2	93.94	46.97	62.50*	3.26	92.44	4.76
Error(pure)	36	27.06	0.75	-	-	-	1.70
Total	44	1941.01	957.73	-	-	-	100

** Significant variable,* Sub significant variable

Table 9.ANOVA and F test for hoop tensile strength

Variable (Z)	Degree of freedom (f_z)	Sum of squares (SS_Z)	Variance (V_Z)	F-ratio (F_Z)	Critical F value at 5% probability	Pure sum of squares (SS_Z')	Percentage contribution (P_Z)
Winding angle (A)	2	44559.31	22279.65	105.84*	3.26	44138.31	24.99
Silica content (B)	2	87077.89	43538.95	206.84**	3.26	86656.90	49.06
Silica particle size (C)	2	32426.11	16213.06	77.02*	3.26	32005.12	18.12
Fibre pretension (D)	2	4983.39	2491.70	11.84*	3.26	4562.40	2.58
Error(pure)	36	7577.90	210.50	-	-	-	5.24
Total	44	176624.61	84733.85	-	-	-	100

** Significant variable,* Sub significant variable

Table 10.ANOVA and F test for pipe stiffness

Variable (Z)	Degree of freedom (f_z)	Sum of squares (SS_Z)	Variance (V_Z)	F-ratio (F_Z)	Critical F value at 5% probability	Pure sum of squares (SS_Z’)	Percentage contribution (P_Z)
Winding angle (A)	2	271324.71	135662.35	452.18**	3.26	270724.67	85.13
Silica content (B)	2	19420.30	9710.15	32.37*	3.26	18820.27	5.92
Silica particle size (C)	2	4097.52	2048.76	6.83*	3.26	3497.48	1.10
Fibre pretension (D)	2	12378.08	6189.04	20.63*	3.26	11778.04	3.70
Error(pure)	36	10800.62	300.2	-	-	-	4.15
Total	44	318021.23	153910.32	-	-	-	100

** Significant variable,* Sub significant variable

In all the above cases the F- ratio, exceeds the critical value hence null’s hypothesis is rejected for all cases.

3.5. Conformation Experiments

The conformation experiments were carried out by keeping the control parameters at optimized levels. The optimized axial tensile strength, hoop tensile strength and pipe stiffness were measured as 40.10MPa, 301.24MPa and 558.05kPa respectively and the above results show good degree of conformance.

4. Finite Element Analysis

The finite element analysis was performed for the above optimized pipes to simulate the underground loading conditions of the pipe. The composite pipe was modeled using multi layered structural linear SHELL 99 element.

The SHELL 99 is an area element which allows multilayer analysis considering the effect of orientation of each layer. The model consists of finite number of filament wound layers and sand layers constructed using the stacking sequence obtained from the filament winding process. However the effect of anisotropy was also considered in calculating material properties for the filament wound layers [9-11].

4.1. Boundary Conditions

The pipe is buried underground in a trench where it is acted upon by an internal pressure of 6 bar magnitude and external load due to soil overburden due to minimum cover depth of 1.5m. The bottom of the pipe is constrained in the vertical direction alone. The load calculation and related details are referred from AWWA M45 standard.

4.2. Nodal Solution

a b c

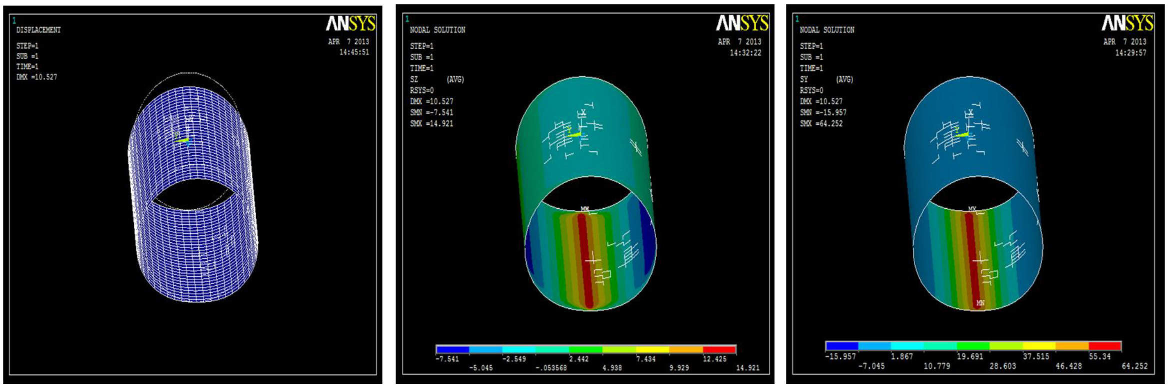

Fig.4. (a) Plot for hoop deformation; (b) Plot for axial stress; (c) Plot for hoop stress.

The nodal solutions obtained for the optimized combination are given in table 11.

Table11. Nodal solutions for optimized pipes

Optimum setting	Maximum axial stress (MPa)	Maximum hoop stress (MPa)	Maximum hoop deflection (mm)
A1 B1 C1 D3	14.921	64.252	10.527
A3 B1 C1 D1	14.479	62.809	15.974
A2 B3 C1 D3	14.728	63.780	10.404

5. Results and Discussions

5.1. Axial Tensile Strength

The optimum combination for axial tensile strength was found out as A1 B1 C1 D3, where silica particle size plays very significant role. This is due to reason that the smaller particle silica size (<300 microns) resulted in better bonding and higher degree of sand compaction. Moreover smaller silica particle size tends to reduce void spaces within the layer; thereby void free composites that exhibit superior mechanical characteristics are obtained.

The finite element solution showed that the optimized pipe had a factor of safety of 2.69 and 4.69 for axial and hoop stresses respectively. The hoop deformation is at 10.53 mm which is well within the 5% deflection (25mm) specified by ASTM D2412.

5.2. Hoop Tensile Strength

The optimal combination for hoop tensile strength was found out as A3 B1 C1 D1, where silica content plays a significant role in deciding hoop strength of the pipe. The silica content is to be kept at low levels for maximizing the hoop strength. This is due to the reason that lower percentage of silica increases the net fiber content and improved bonding between the composite layers. Increasing sand content will tend to promote de-lamination between various layers of the composite thereby hoop properties would be compromised.

The finite element solution showed that the pipe optimized for hoop strength will have a factor of safety of 2.77 and 4.80 for axial and hoop stresses respectively. The hoop deformation is at 15.97 mm which is also within the 5% deflection.

5.3. Pipe Stiffness

The optimized combination for pipe stiffness was found out as found out as A2 B3 C1 D3, where the winding angle plays a significant role in determining stiffness of the pipe. The winding angle is to be kept at intermediate levels of the range as it is seen that winding angles closer to hoop winding tend to produce higher hoop modulus at the expense of axial modulus. The converse effect is observed at low winding angles. Hence by keeping the winding angle at optimum range sets even distribution of above modulus thereby high pipe stiffness value is observed.

The finite element solution showed that the pipe optimized for stiffness will have a factor of safety 2.72 and 4.72 for axial and hoop stresses respectively. And the hoop deformation is 10.40 mm which is lowest value of all observations which indicates that the pipe has more stiffness.

6. References

[1] Cohen, D., "*Influence of filament winding parameters on composite vessel quality and strength,*" Alliant Techsystems Inc., Magna, UT 84044, USA.

[2] Mertiny, P., Ellyin, F., "*Influence of the filament winding tension on physical and mechanical properties of reinforced composites,*" University of Alberta Edmonton, Canada.

[3] Rousseau, J., Perreux,D., Verdiere, N., "*The influence of winding pattern on the damage behaviour of filament wound pipes,*" Composites Sciences and Technology(1999).

[4] Dobrzanski, L, A., Domagala, J., Silva, J, F., "*Application of Taguchi Method in the optimization of filament winding of thermoplastic Composites,*" International Scientific Journal, Committee of Material science of the Polish academy of Sciences.

[5] Richard Crowson., Jack Walker., "*Handbook of Manufacturing Engineering,*", Second edition.

[6] Bala Murugan Gopalsamy., Biswanath Mondal., and Sukamal Ghosh., "*Taguchi Method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel,*" Journal of Scientific & Industrial Research.

[7] Mohd,Amri Lajis., Mohd.Radzi, H.C.D., Nurul Amin, A.K.M., "*The Implementation of Taguchi Method on EDM Process of Tungsten Carbide,*" European Journal of Scientific Research.

[8] Tsao, C.C., Hocheng, H., "*Taguchi analysis of delamination associated with various drill bits in drilling of composite material,*" International Journal of Machine Tools & Manufacture.

[9] Satheesh Kumar Reddy, P., Nagaraju, Ch., Harikrishna, T., "*Optimum design and analysis of Filament Wound composite tubes in Pure and Combined Loading,"* International Journal of Engineering Research & Technology.

[10] Xia, M., Kemmochi, K., Takayanagi, H., "*Analysis of filament-wound fiber-reinforced sandwich pipe under combined internal pressure and thermomechanical loading,"* Elsevier Publications.

[11] Emrah Salim Erdiller., "*Experimental Investigation for Mechanical Properties of Filament Wound Composite Tubes,"* Middle East Technical University.